Spruce Improvement Through Vegetative Propagation: A Story of Co-operation

August, 1985

Phase I of an Evaluation of the Applied Research and Development Projects of the Canada – Ontario Forest Management Subsidiary Agreement

Guy Smith

Forest Resource Development Agreement
Entente sur la mise en valeur de la ressource forestière

Canada

Ontario

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Canada

Ontario

August 14, 1985

Messrs. K.A. Armson and J.H. Cayford
Co-chairmen, Management Committee
Canada-Ontario Forest Resource
Development Agreement (CORFDA)

Dear Sirs:

Herewith is the first phase of my evaluation which was requested by the COFRDA Management Committee.

This phase examines in detail the project "Tree Improvement Through Vegetative Propagation". This was the largest single project of the Assessment Program of the Canada-Ontario Forest Management Subsidiary Agreement.

Sincerely,

Guy Smith

Guy Smith

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

Letter of Transmittal 1
Acknowledgements ii
Table of Contents iii
Tables and Figures v

INTRODUCTION 1

VEGETATIVE PROPAGATION OF CONIFERS IN ONTARIO:
An Historical Overview 2

Laying the Groundwork 1939-1969 2
Vegetative Propagation: A Promising Future 1969-1972 ... 4
Controlled Crosses and Super Seedlings 1972-1978 4

THE PROJECT FUNDED UNDER THE CANADA-ONTARIO
FOREST MANAGEMENT SUBSIDIARY AGREEMENT 10

1) Project Progress at Orono Nursery 11
Operational Rooting of Cuttings 12
Orono's Vegetative Propagation Centre 12
Development and Transfer of Rooting Technology 15

2) Project Progress at Swastika Nursery 17
Operational Rooting and Technology Transfer 18

3) Project Progress in the Northern Region 20
The Progeny Tests 20

THE CURRENT STATUS OF SPRUCE VEGETATIVE
PROPAGATION IN ONTARIO 21

The Northern Clonal Forestry Centre 21
The Outlook for Orono and Swastika Nurseries 23

THE IMPACT OF THE CANADA-ONTARIO FOREST MANAGEMENT
SUBSIDIARY AGREEMENT ON SPRUCE IMPROVEMENT THROUGH
VEGETATIVE PROPAGATION 24

Recommendation 1 24
Recommendation 2 27
Recommendation 3 29

CLONAL FORESTRY AND TREE IMPROVEMENT IN ONTARIO:
WHAT LIES AHEAD? 30

Future Clonal Forestry 30
Research and Development Needs 31

CONCLUSION 33

APPENDIX A - Bibliography of Reports Produced Through the COFMSA Tree Improvement Through Vegetative Propagation Project

APPENDIX B - People Interviewed for Project Analysis

LITERATURE CITED

TABLES AND FIGURES

Allocation of COFMSA Funds by Program 10
Summary of Costs for Orono's Vegetative Propagation Centre 12
Production Figures for Rooted Cuttings and Regular Seedlings at Orono Nursery's Vegetative Propagation Centre 14
Production Cycle of Black Spruce Cuttings for Progeny Tests in 1981-82 15
Production of Grafts at Orono Nursery 17
Production of Black Spruce Juvenile Cuttings of Swastika Nursery 19
Outline of Tree Improvement Through Vegetative Propagation 24
Summary of COFMSA Funding to Tree Improvement Through Vegetative Propagation, 1980-1984 25
Original Estimates of Annual Expenditures for Project 28
Actual Annual Expenditures for Project 28

INTRODUCTION

Throughout human endeavour, cooperation is often the key to success. Even with scarce resources, people working together with a common goal may produce important innovations and introduce valuable new ideas. In the worlds of politics, religion, business and science and technology, cooperation is vitally important in the 1980's.

In Ontario, nowhere is the necessity for cooperation more evident than in the management of forest resources. If forest management benefits are to be realized, cooperation must occur between the government and the forest industry, between the various regions of the Province, and, perhaps most importantly, between the federal and provincial levels of government.

This report focuses on the development and implementation of a single branch of forest management - coniferous tree improvement. Specifically, the report deals with the improvement of spruce trees using the techniques of vegetative propagation.

Spruce improvement through vegetative propagation has an intriguing history and a promising future. Its success in Ontario is the result of various people working together. Moreover, the future of spruce improvement work in Ontario will be determined by the extent to which the government and the private sector help one another.

This report directs special attention to federal-provincial cooperation. The two levels of government jointly supported spruce improvement through the Canada-Ontario Forest Management Subsidiary Agreement. The effectiveness of this agreement is reflected in the success of the projects it supported. Ultimately, this success depended upon the effectiveness of coopertion between people.

VEGETATIVE PROPAGATION OF CONIFERS IN ONTARIO: AN HISTORICAL OVERVIEW

Vegetative propagation produces many identical off-spring, or ramets, from a single parent plant, or ortet. Together, the off-spring and the parent are called clones, because they share an identical genetic constitution.

Rooting of cuttings is a widely-used method of vegetative propagation, and has been applied in poplar and willow regeneration work for many years. By this method, cuttings are usually taken from the stem of a parent or donor, and then planted in a soil medium. If conditions are favourable, roots will form at the base of the stem cuttings, resulting in "rooted cuttings": new individuals which are genetically identical to the parent from which they were taken.

Rooting of cuttings is one part of the science and practice of clonal forestry. A comprehensive defense of clonal forestry has been written by W.J. Libby and R.M. Rauter (1984). Their article explains 18 advantages associated with the use of clones in forestry. One of the major advantages is the contribution of clones to tree improvement programs.

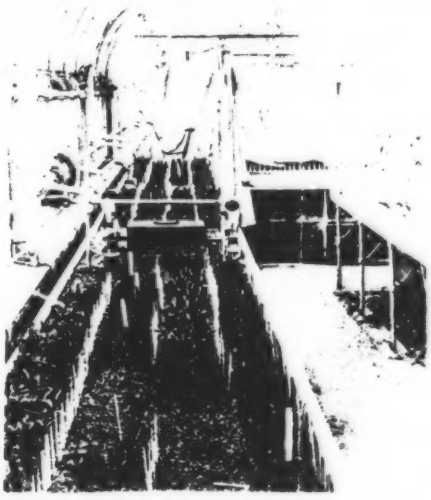
In Ontario, pioneering attempts to successfully root cuttings of coniferous species began in the 1930's. Today, the practice of vegetatively propagating spruce trees is well-developed, and has been applied in a spruce improvement program. A long history of developmental work is responsible for the present success of coniferous vegetative propagation in Ontario.

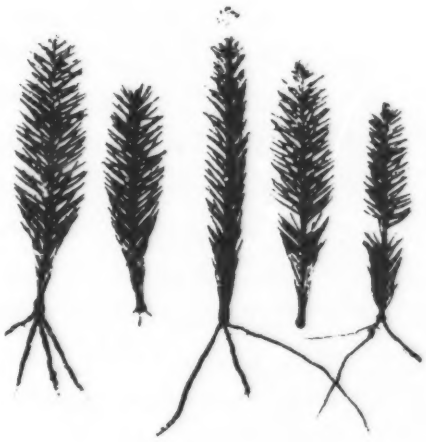
Laying the Groundwork 1939 - 1969

In Canada, the earliest published experiments on rooting of conifer cuttings are those of J.L. Farrar and N.H. Grace. Their work from 1939 to 1942 was part of a cooperative project of the Sub-committee on Forest Tree Breeding, National Research Council of Canada. Early experiments dealt with cuttings from 19 year old Norway Spruce in plantations at the Petawawa Forest Experiment Station of the Dominion Forest Service.

Farrar and Grace proved that Norway spruce cuttings taken in the period from October to April can be rooted in appreciable numbers and propagated in a greenhouse. A number of factors influenced rooting success, and optimal conditions varied each month and each year. The rooting medium and the size of cutting were especially important factors. Farrar and Grace found that short cuttings rooted better than long cuttings, and that lower lateral twigs root better than cuttings from other parts of the tree. There was variable response to chemical growth stimulants, depending upon the time of year when cuttings were taken.

This research with Norway spruce, and subsequent work by the same authors with white pine and white spruce, proved the potential for rooting of conifer cuttings. It was evident from the results, however, that many factors influenced rooting success. This variability left many more questions for researchers to answer.





General view of the greenhouse at the Petawawa Forest Experiment Station showing 3200 cuttings in the bench (above)

Some of the Norway spruce rooted cuttings (right)

(Source: Farrar, 1939)

Unfortunately, the Second World War brought a halt to vegetative propagation work in Ontario. It would be the late 1960's before major efforts would resume.

In the meantime, studies conducted outside of Canada, particularly in the U.S.A., discovered that young material roots better than old (Thimann and Delisle 1939; Fielding 1954). It was also observed that tree-to-tree variation is extreme with variable results from one year to the next (Duffield and Liddicoet 1948; Patton and Riker 1958), and the effect of time of collection of cuttings is depended on the species used (Doran 1957; Nienstaedt et al 1958).

Vegetative Propagation: A Promising Future 1969 - 1972

The groundwork was laid, and by the late 1960's Ontario began to use rooted cuttings in a conifer improvement program. With a growing shortage of seedlings for reforestation, rooting cuttings was an alternative means of stock production which could not be overlooked.

Experiments to further determine the optimal conditions required for rooting spruce cuttings were conducted by R.M. Rauter at the Maple Research Branch of the Ontario Department of Lands and Forests, (now the Ontario Ministry of Natural Resources). She found successful rooting results from cuttings of 3-year-old spruce species, and like earlier researchers, she noted extreme tree-to-tree variation within the same species (Rauter 1971).

The results of Rauter's trial indicated a promising future for vegetative propagation programs, and provided encouragement for the greater use of rooted cuttings.

Controlled Crosses and Super Seedlings 1972 - 1978

Now that the rooting of conifer cuttings had proven successful, the way was open for trying vegetative propagation in a tree improvement program.

Preliminary selections in a tree improvement program choose the best phenotypes. A phenotype is the physical appearance of an individual; it is the expression of hereditary traits. A genotype, on the other hand, is the genetic constitution of an individual. As a tree grows, its environment influences the expression of genetic characteristics. The trees that are initially selected on a given site exhibit the finest growth rate and form compared to neighbouring trees on that site.

Following the preliminary field selections, tree improvement programs aim at identifying "plus" trees. Among the best phenotypes selected in the field, the "plus" trees are those which are genetically superior. The superiority of the "plus" trees results from superior genetic constitution and not merely from a favourable growing environment. Thus "plus" trees are good genotypes.

One method of identifying genetically superior conifers involves producing seed from select trees that have been cultivated in a seed orchard. Ontario's conifer improvement program has used this method of controlled breeding. Through this approach, superior trees growing in the field are selected from among neighbouring trees on the basis of form and height growth. Large cuttings, called scions, are taken from these select trees and then grafted to the root stock of another tree. A number of these grafts are then planted together as an orchard, and the field trees represented by each graft are carefully recorded.

If pollination is permitted to occur freely amongst individuals in the orchard, the process is random, and the male parent of any given seed is unknown. Such reproduction in a seed orchard is called "half-sib crossing", because only one parent is known.

Alternately, pollination amongst individuals in the orchard may be accomplished artificially. Artificial or controlled pollination, usually consists of enclosing female flowers in plastic bags that are sealed around the branch, just below the flower. Male pollen from specific trees is selectively introduced into the sealed environment of the female reproductive organ. Thus, pollination can only occur

between two known parents. Because the parent trees of the resulting seed are both known, controlled pollination is called "full-sib crossing".

The trees selected in the field were good phenotypes; they were selected, because in their particular growing environment they displayed desirable growth features. However, the genetic superiority of these trees is uncertain. Only through monitoring the growth of their offspring in field trials can one be certain of their true genetic worth.

Vegetative propagation plays an important role in evaluating the genetic quality of seed orchard stock. Often a seed orchard will not yield enough seed for an effective trial. However, the available seed may be germinated with cuttings subsequently clipped from the seedlings and rooted at several time intervals. By this means, over a two-year period, 100 rooted cuttings may be produced for each seed germinated (Department of Regional Economic Expansion, 1980).

As a result, many clones of each seed orchard offspring are available for field testing. When clones are produced from offspring of seed orchard trees, the field tests with those clones are called "progeny tests".

In 1972, a seed orchard was established at Glencairn, in Southern Ontario. This orchard contained black spruce genotypes selected in the Northern Region of the Province. Through controlled pollination, a limited amount of seed was obtained from the orchard in the late 1970's. This was an insufficient amount of seed for a conventional progeny testing program. However, through vegetative propagation many seedlings could be produced from this small batch of seed. The idea of vegetative propagation was especially appealing in the late 1970's because of the scarcity of tree seed in the Province.

The Glencairn seed orchard became Ontario's first source of seed for clone production and progeny testing of black spruce. The first clones developed from this orchard are still being used in today's clonal forestry operations.

Another side of the conifer improvement program was initiated by R.M. Rauter of the Forest Research Branch at Maple. She was responsible for administering the "Super Seedling Program", in cooperation with six Ontario tree nurseries. At each nursery, the black and white spruce seedlings with the best height growth, diameter, and branching habit were selected. One tree out of every 100,000 was chosen. Initial seletion was accomplished by sighting across the surface of the nursery beds and identifying the super seedlings that dominated over all of the others.

The advantage of the Super Seedling Program was that cuttings would be clipped directly from the super seedlings, rooted and outplanted in large numbers a short time later. These outplanted cuttings could be grown as a trial, to test the genetic quality of the parent material from which the cuttings were made. Over time, superior performance of the outplanted clone would indicate superior genetic composition of the parent plant. The superior clones could thereby be identified, and inferior clones discarded.

Under the Super Seedling Program field tests could be established within five years of nursery selection. In contrast, at least twice the time was required for a conventional controlled pollination tree improvement program (Rauter 1974).

From 1975 to 1977, cuttings were taken from the select trees of the Super Seedling Program. Rooting percentages, however, "were low, with few cuttings surviving" (Phillion 1982). Nontheless, the original super seedlings from each nursery were outplanted with average seedlings from the same nursery. Periodic height surveys indicated that the super seedlings maintained their total height superiority over the average seedlings (Phillion 1982).

Putting Down Roots 1978 - 1980

Rooting of cuttings certainly had potential in conifer improvement work, but some refinements were in order before the method could be expanded to an operational scale. Most importantly, techniques were needed to improve rooting success and to permit the mass production of trees for out-planting.

Rooting of cuttings had been ongoing since 1975 under Faculty of Forestry Professor K. Armson at the University of Toronto's Glendon Hall Research Laboratory. Unlike most earlier experiments, this work concentrated on cuttings from juvenile seedlings, that is, seedlings in their first year of growth. Previous work by Rauter (1971, 1974) used 3-and 4-year old black spruce seedlings for cuttings. Work by Zsuffa (1974) used cuttings of jack pine from 6 and 10 year old plantation trees.

In a preliminary study at Glendon Hall (Armson et al. 1975), 20 cuttings of black spruce were taken from juvenile greenhouse seedlings. Under conditions of controlled temperature and humidity, the rooting success was 75 percent. This was greater than the 12 to 62 percent rooting success for cuttings of 3-year-old spruce found by Rauter (1971). Favourable results were also obtained when juvenile cuttings of jack pine were planted and rooted under controlled humidity, temperature and light conditions. The overall rooting success of 76 percent represented a dramatic improvement over the 6.6 percent rooting success of 6-and 10-year-old jack pine found earlier by Zsuffa (1974).

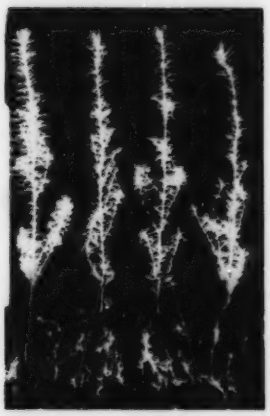
In the late 1970's two University of Toronto graduate forestry students based their Master's Theses on rooting of conifer cuttings. Pérez de la Garza (1977) and Fung (1978) experimented with vegetative propagation of black spruce, jack pine and larch. They found that rooting success could be increased by using cuttings from seedlings in their juvenile state, prior to the onset of dormancy or bud set. Initiation of roots took place normally within 30 to 40 days from the time of taking the cutting. The best rooting medium was a 1:1 mixture of commercial peat and vermiculite. A mini-greenhouse arrangement with equipment for periodic mist-irrigation was found to be suitable for optimum rooting. The size of cutting affected plant size - the larger the cutting, the more vigorous the resulting plant (Armson et al. 1980).

These conclusions underly the basic techniques used in Ontario today for rooting spruce cuttings.

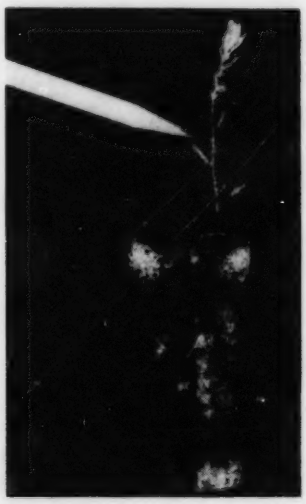
By 1979 it was apparent that the time was ripe for Ontario to support a major coniferous tree improvement program. In addition to a growing demand for reforestation, the province recognized that "genetically improved material should form an increasingly large proportion of the conifer planting stock" (Armson et al. 1980). Accordingly, a 10 month operational trial was conducted at Orono Nursery by K. Armson, M. Fung and W. Bunting. Over the trial period, 85,000 seedlings were grown in a greenhouse and from those, two sets of cuttings were made to propagate almost half a million seedlings.

In July of 1979, 2,000 rooted cuttings were out-planted in Cochrane District of Northern Ontario in a trial with conventional black spruce seedlings. In October of that year the planting site was assessed and survival of the rooted cuttings was found to be 90 percent.

With no doubt about the feasibility of operational rooting of spruce cuttings, Orono Nursery promptly embarked on a production program in October, 1979. By the summer of 1980, approximately 200,000 rooted cuttings were available for progeny trials and general reforestation.



Rooted cuttings 16 weeks from the date of propagation



A 10-week old seedling ortet before the first cutting was taken. The pencil tip indicates where the cut was made.

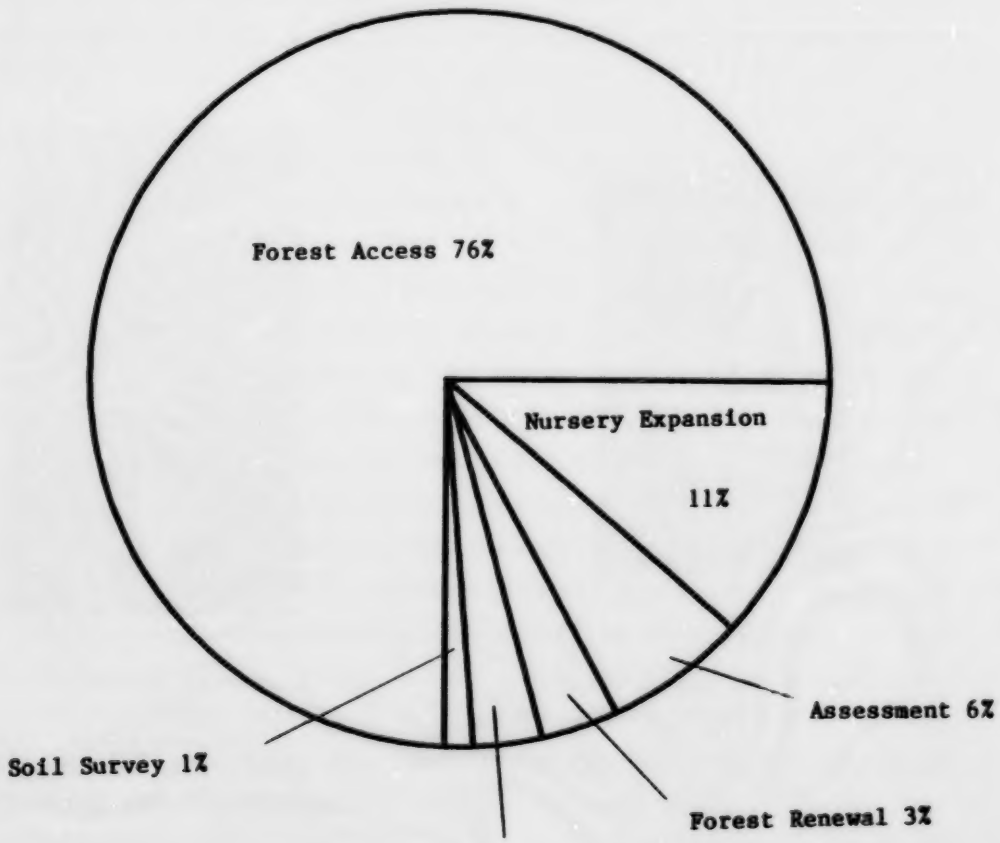
(Source: Fung, 1980)

THE PROJECT FUNDED UNDER THE CANADA-ONTARIO FOREST MANAGEMENT SUBSIDIARY AGREEMENT

The Canada-Ontario Forest Management Subsidiary Agreement, or COFMSA, was a landmark federal-provincial initiative to enhance the management and improve the utilization of Ontario's forests. Signed December 8, 1978, this five-year agreement set out to "coordinate and concentrate relevant federal and provincial programs" (Department of Regional Economic Expansion 1982). The cost of the Agreement, amounting to $82,236,500.00, was borne equally by Canada and Ontario. Figure 1 illustrates the percentage of total COFMSA funds allocated amongst the six programs of the Agreement.

Figure 1

Allocation of COFMSA Funds by Program



"Tree Improvement Through Vegetative Propagation" was a project approved by the COFMSA Management Committee on April 29, 1980. The stated objective of the project was "to produce and evaluate clonal stock of superior seed source". The project was classified under COFMSA's Assessment Program as:

> Applied pilot research designed to establish field capability and to identify and rectify operational problems involving forest management techniques and equipment (Department of Regional Economic Expansion 1982).

The Assessment Program included 23 projects of this classification. These projects varied from basic research, such as forest stand structure and prescribed fire research, to operational activities involving the development of cone harvesters and planting machines. "Tree Improvement Through Vegetative Propagation" was neither a basic research project nor an operational trial. With several other Assessment Program projects, the vegetative propagation work incorporated elements of research, development and application.

This project received 25% of the Assessment Program's funds. This made it the largest project in the Program and clearly a top priority for COFMSA's Management Committee. The emphasis on tree improvement in Ontario, and the rising demand for genetically improved planting stock in the Northern Region were responsible for the high priority given this project.

1) Project Progress at Orono Nursery

By 1980, Orono Nursery in Southern Ontario (approximately 80 km east of Toronto) had become the province's focus of expertise and technology development in the field of rooting conifer cuttings. It was at Orono that the Provincial Government first tested the feasibility of vegetatively propagating conifers, and at Orono that the first large-scale operational trial of rooting juvenile cuttings was conducted by the Faculty of Forestry, University of Toronto. Hence, the nursery was well acquainted with the techniques and facilities required for successful rooting of cuttings.

Operational Rooting of Cuttings

It is not surprising that Orono was a key participant in the COFMSA project "Tree Improvement Through Vegetative Propagation". Under the project Orono served a vital role in meeting the objective of producing and evaluating clonal stock of superior seed source. The Northern Region of the Ministry of Natural Resources was responsible for the tree improvement work of selecting spruce trees for testing and undertaking the progeny tests, using clonal stock. Orono was responsible for providing this clonal stock, in large numbers, for progeny testing. Another function of Orono was to maintain the mother stock in a juvenile state by rooting successive cuttings from donor plants. To fulfill its role in the project Orono required an enlarged greenhouse facility, specifically designed for mass-producing spruce cuttings.

Orono's Vegetative Propagation Centre

The W.R. Bunting Vegetative Propagation Centre at Orono Nursery was completed in April 1981. Funded entirely by COFMSA, at a total cost of $309,903.61, the complex included an aluminum header house servicing two 3600 square foot, fully equipped greenhouses (Table 1). Agreement money also contributed to the cost of building a holding area for storing the cuttings produced in the greenhouses.

Table 1

Summary of Costs for Orono's Vegetative Propagation Centre

1.	Site services	$ 6,843.42
2.	Header house	72,645.00
3.	Greenhouses	88,786.00
4.	Heating system	39,590.00
5.	Plumbing system	17,902.40
6.	Electrical services	31,695.19
7.	Miscellaneous equipment/material/ services for greenhouses and header house operations	52,441.60
	TOTAL	$ 309,903.61

(Source: Engineering Services, Central Region, Ministry of Natural Resources, 1981.)

Upon completion of the greenhouse the vegetative propagation program commenced at Orono. Propagation material came from three sources:

i) Seed produced at the seed orchard in Glencairn. This seed was produced by controlled pollination of grafts that had been taken from superior field trees selected in the Northern Region.

ii) Plantation trees in the 6-10 year age class that exhibited very high growth rates.

iii) Super seedlings which had been selected through the "Super Seedling Program" and outplanted in nursery holding areas for several years.

The bulk of the material used for propagation at Orono came from the first source: seeds produced by controlled crosses at Glencairn. This propagation material was preferred over the other sources because it permitted propagation using juvenile trees - the proven method for rooting cuttings at Orono. Cuttings taken from trees older than the juvenile stage had proved less successful in the past.

The Super Seedling Program, while still viable, was gradually de-emphasized in the early 1980's. Tree improvement specialists in the province recognized that, while super seedlings yielded clonal progeny for testing in a short time period, they did not necessarily represent superior genotypes. Rather, a superior tree needed to stand the test of time to properly judge genetic quality. The seedling stage was too early in a tree's development to make a confident assessment.

Thus in the early 1980's, attention was turned from the Super Seedling Program to rooting juvenile cuttings. Juvenile cuttings provided the best of both worlds: progeny tests of mature, field-selected parent trees, and rapid mass production of cuttings taken from juvenile seedlings. This shift in emphasis was reflected in Orono's first season - over 138,000 rooted cuttings were produced from juvenile cuttings and roughly 1,000 rooted cuttings were produced from cuttings of super seedlings and plantation trees. Production figures for subsequent years appear in Table 2.

Table 2

Production Figures for Rooted Cuttings and Regular Seedlings at Orono Nursery's Vegetative Propagation Centre 1981 - 1984

(Spruce, Pine and Larch Species)

Year	Rooted Cuttings: Juvenile Cuttings	Rooted Cuttings: Super Seedlings and Plantation Cuttings*	Regular Seedlings	Total
1981	138,853	1,000	-	139,853
1982	103,777	1,000	150,000	254,777
1983	153,827	1,000	-	154,827
1984	16,018	-	61,837	77,855
TOTAL	412,475	3,000	211,837	627,312

* Annual averages based on estimated 1981-83 total 3,000.

In 1981, the Ministry of Natural Resources hired Bernie Phillion as a Vegetative Propagation Specialist at Orono Nursery. Together with Nursery Technician John deWitt and Superintendent Bill Bunting, Phillion set out to optimize the production of rooted cuttings for Northern Region progeny testing.

On their first attempt, it took the team at Orono nearly three years to achieve their goal of producing 140 ramets of each clone. Subsequent attempts at Orono achieved the 140 ramets goal more quickly. Table 3 outlines the production of 140 ramets per clone at Orono over an 11 month period.

Table 3

Production Cycle of Black Spruce Cuttings for Progeny Tests in 1981-82 (Phillion 1983)

Date	Activity	Total Number	Number/Clone
October 1981	Seed Sown	1,900	
November 1981	Germination Count	850	1
March, 1982	First Cutting	35,700	42
August, 1982	Second Cutting	119,000	140

Development and Transfer of Rooting Technology

The improved results at Orono are the product of diligent efforts to refine and develop the practice of rooting cuttings. During their time at Orono, Bernie Phillion and John deWitt made full advantage of their opportunity to expand upon the techniques established previously by researchers.

There was much to be learned from the experience of mass-producing juvenile cuttings for progeny testing. According to Phillion, "We sometimes learned the hard way - there was a problem with inexperience". Nonetheless, through gradually overcoming this inexperience, expertise was developed, and the practice of rooting cuttings was greatly improved over the period of COFMSA funding.

Phillion conducted numerous experiments which helped in understanding the requirements for rooting cuttings. The results of many of these experiments were documented and published. In total, 39 reports were written by Bernie Phillion while he was at Orono. These reports all document studies conducted under the Tree Improvement Through Vegetative Propagation project of COFMSA at Orono Nursery.

The reports cover a range of experiments investigating the growth and development of both cuttings and their donor plants. Lighting, rooting media, fertilization, growth stimulants, cultural practices, and species choice are some of the areas of study discussed in the reports. A complete bibliography of the reports is found in Appendix A. It should be noted that the studies at Orono were small in scale, and conducted on the side while operational rooting was in progress. Hence, none of these studies are scientific landmarks. They were published in meeting proceedings and technical nursery notes, not scientific journals. The true worth of these studies was not academic but rather technical, as agents of technology transfer. "Tree Improvement through Vegetative Propagation" may have been classified as applied research and development under COFMSA, but the priority of the project was to produce superior trees, not scientific reports.

A large component of Orono's work under the COFMSA project was technology transfer. In 1982, when Swastika Nursery (near Kirkland Lake) entered into the project, Bernie Phillion and John deWitt were responsible for introducing Orono's technology to the new facility at Swastika. In addition, Phillion presented papers to the 1982 Ministry of Natural Resources Nurserymen's meeting, and the 1982 meeting of the International Plant Propagation Society, discussing Orono's vegetative propagation work.

Unfortunately, a hiring freeze was imposed in the Ministry of Natural Resources in 1983. This left Bernie Phillion without a technician for the rest of the COFMSA period and limited the extent to which he could promote Orono's program.

As tree improvement work progressed in the Northern Region, the demand on Orono for grafted stock increased. Scions cut from superior black spruce trees in the Northern Region were shipped to Orono, grafted to root stock and nurtured in a greenhouse. When ready for out-planting, the grafted stock was shipped to the Northern Region and used in seed orchards for controlled pollination.

Once Swastika Nursery was operationally rooting cuttings, Orono Nursery reduced its production of black spruce juvenile cuttings, and increased graft production.

Orono's production of grafts is given in Table 4.

Table 4

Production of grafts at Orono Nursery

Year	Number of Grafts	Species
1981	1 859	Black spruce, White spruce
1982	2 007	Black spruce
1983	8 625	Black spruce, White pine
1984	13 136	Black spruce, White spruce, White Pine, Scots pine, Larch
TOTAL	25 627	

2) Project Progress at Swastika Nursery

In 1981 the Swastika Forest Station, near Kirkland Lake, entered into the Tree Improvement Through Vegetative Propagation Project. COFMSA funded construction of a greenhouse at a cost of $84,456.

The Swastika facility, however, was not designed specifically for rooting of cuttings. In fact, the heating and irrigation systems were inadequate for vegetative propagation because they did not maintain the sensitive balance of temperature and humidity required by cuttings. Because of the structure's high roof, air circulation was excessive, and increased the difficulty of maintaining optimal rooting conditions. Until 1985, there were no proper benches for supporting the trays of seedlings above the ground - concrete blocks or wooden pallets were used instead.

Obviously, the Swastika greenhouse was to be used only temporarily for rooting of cuttings. The intention was to undertake a trial, to develop the practice of rooting cuttings in Northern Ontario.

Operational Rooting and Technology Transfer

In 1981, parent trees from Orono were shipped to Swastika for the first batch of cuttings. Although rooting occurred quickly, the success was only 50%. Subsequent efforts at Swastika using modified rooting techniques raised success to 75%.

When Gilbert Leveille began working as a technician at Swastika Nursery in 1979, he knew very little about nursery practices, and had no experience with vegetative propagation. In 1981, however, he assumed responsibility for the vegetative propagation work in Swastika's newly constructed greenhouse. Rooting of conifer cuttings was a new phenomenon, and only a handful of people in the south were familiar with the technology developed at Orono Nursery.

There is much to learn when starting a juvenile cuttings program. Fortunately, Leveille was able to gain knowledge and hands-on experience from people who had learned and were continuing to learn from experience at Orono. Bernie Phillion and John deWitt assisted Leveille in establishing the trials at Swastika Nursery. This personal interaction, including demonstrations for the workers at Swastika, slide presentations, and numerous discussions and tips, effectively transferred the technology of rooting cuttings from Orono to Swastika Nursery. In addition, the published and unpublished reports of Phillion et al. served to disseminate new knowledge and innovations concerning rooted cuttings.

Of course, not everything that worked at Orono would work at Swastika. In Swastika, Leveille was dealing with a different climate and a different greenhouse environment from Orono. Without re-inventing the practices developed at Orono, Leveille experimented with modifications of Orono's techniques. Oftentimes he had to "make his own rules" to achieve rooting success. Production figures for Swastika Nursery are given in Table 5.

Table 5

Production of Black Spruce Juvenile Cuttings
at Swastika Nursery

Year	Number of Cuttings Shipped
1982	92 000
1983	426 000
1984	57 000 *
1985	50 000 **

* 45 000 shipped to Northern Clonal Forestry Centre, Moonbeam
** to be shipped in late 1985.

The successful development of rooting conifer cuttings at Swastika Nursery was an important step for the COFMSA - funded tree improvement program. Progeny testing could be conducted more quickly and efficiently by mass producing juvenile cuttings at Swastika instead of Orono. Tree improvement activities could concentrate in the Northern Region, where the progeny testing, and ultimately the production planting would occur.

Orono Nursery continued to play an important but somewhat different role in the Tree Improvement Project. Orono was responsible for grafting spruce scions for the seed orchards being established by Larry Miller, the tree improvement professional in the Northern Region.

In 1983, Swastika nursery began to supplement Orono's rooted cutting shipments to Northern Region progeny tests. By 1984, Orono reduced its production of cutting stock. Swastika was preparing to ship a crop of over 30,000 rooted spruce cuttings to a new private sector greenhouse, built especially for vegetative propagation, near Kapuskasing.

3) Project Progress in the Northern Region

During the COFMSA era, the Northern Region of the Ministry of Natural Resources was responsible for using the clonal stock produced at Orono and Swastika Nurseries for progeny testing. Progeny tests could identify the original plus tree selections that were genetically superior. Seed from controlled crosses of these tested trees could be collected, and seedlings produced from this seed. Subsequent vegetative propagation could focus on mass-producing clones of these genetically superior seedlings. Without the progeny test plantings in the Northern Region, the tree improvement project was incomplete.

The Progeny Tests

The first progeny test of COFMSA's "Tree Improvement Through Vegetative Propagation" project was in 1982. Unfortunately, this first test was a failure. The site chosen for planting was less than ideal, and the management and record-keeping of the test planting was poorly handled. It is essential in a test-planting to carefully record, by clone, every single rooted cutting being outplanted. The clone must in turn be recorded according to the seed produced by cross pollintion in the seed orchard. The seed orchard trees (grafts) must be identified according to the field trees from which they were taken. This is a laborious process, yet nonetheless crucial to an effective tree improvement project. Failure to document, record and file each stage in the process may result in the loss of years of work.

The Northern Region's subsequent progeny tests, in 1983 and 1984, proved more successful than the first. The results of these tests will help to identify superior parent trees. In addition, the tests will provide some basic genetic information about genotype-site interaction which will be very valuable in the design of future progeny tests.

THE CURRENT STATUS OF SPRUCE VEGETATIVE PROPAGATION IN ONTARIO

The Northern Clonal Forestry Centre

The Northern Region of the Ministry of Natural Resources, Ontario's leader in conifer tree improvement, has big plans for clonal forestry in the Province. In 1983, planning commenced for a $1.4 million greenhouse complex in the Region, designed for mass producing rooted cuttings for reforestation.

The Northern Clonal Forestry Centre was completed in November 1984, in Moonbeam, near Kapuskasing, Ontario. Owned and operated by the private sector, the Centre is capable of producing one million rooted cuttings annually. When the project was contracted out, the Northern Region set strict design and construction guidelines. The greenhouse, just under 23,000 square feet in size, is specially designed for rooting juvenile cuttings. It is equipped with a heating and automatic mist-irrigation system to regulate temperature and humidity conditions. If the Region's demand for genetically improved stock increases, the clonal centre is designed to double in size.

The Clonal Centre's Manager is John deWitt, the young technician who worked with Bernie Phillion at the Orono Nursery's innovative vegetative propagation facility during the COFMSA era. Through his experiences at Orono, deWitt acquired valuable expertise with rooting juvenile cuttings. His background in vegetative propagation, along with his enthusiasm for managing his own greenhouse, made deWitt an obvious choice for Manager of the Clonal Centre.

John deWitt relies upon the Ministry of Natural Resources to supply the donor trees to his facility. Late in 1984, Swastika Nursery shipped 30,000 black spruce donor trees to the Northern Clonal Forestry Centre. Swastika had maintained a stock of spruce clones in a semi-juvenile state of growth by repeatedly rooting cuttings from clonal stock developed at Orono Nursery. The juvenile spruce clones at Swastika were suitable for the Northern Clonal Forestry Centre to use as donor trees for their first crop of juvenile cuttings.

The Northern Clonal Forestry Centre's first crop was ready in June, 1985. This crop of 250,000 rooted cuttings will be used strictly for clonal tests. In the spring of 1986 one million rooted cuttings will be produced by the centre. One quarter of a million of these will be used for clonal tests, while the remaining 750,000 will contribute to production reforestation in the Northern Region.

The clonal tests will aim at screening-out the best clones from the 11 families represented in the clonal centre's stock. (These tests should not be confused with progeny tests which select for the best parents in a full-sib seed orchard.)

Sixty million seedlings are planted annually in the Northern Region. The Northern Clonal Forestry Centre will supply 1.7 percent of this planting stock. This may seem a small figure. However, Rauter (1985) estimates that, within 15 years, 35% of the provincial planting program for black spruce should be rooted cuttings.

Cooperation between the Northern Clonal Forestry Centre and the Ministry of Natural Resources is essential if the ambitious new clonal forestry project is going to succeed. The Clonal Centre is somewhat ahead of its time, because a definitive selection of genetically superior families and clones has not been made. Progeny testing is still at an early stage, at least five years from identifying with confidence those spruce clones which are truly "winners".

Vic Wearn is the Spruce Program Forester with the Ministry of Natural Resources' Northern Forest Development Group. He is responsible for spruce improvement in the Northern Region. His work involves establishing seed orchards, conducting controlled crosses, coordinating vegetative propagation work, and overseeing progeny tests and production out-planting.

For Wearn "The Northern Clonal Forestry Centre is too good an opportunity to pass up". The Centre not only provides him with 250,000 rooted cuttings annually for test planting, but with an additional 750,000 clonal seedlings which may be closely monitored in comparison with conventional seedling stock after out-planting.

Wearn will ensure that the Centre's genetically-improved stock gets planted on ideal sites with good site preparation and tending operations after planting. Some of the Centre's stock will be planted on the forest management agreement planting operation of Abitibi-Price Inc. The company has agreed to assist in monitoring the growth and development of this plantation.

Thus, the new Clonal Centre not only provides a source of production planting stock, but also an invaluable opportunity to further the development of provincial tree improvement practices.

The Outlook for Orono and Swastika Nurseries

In time the Northern Clonal Forestry Centre will become self-sufficient, and will no longer rely upon donor trees shipped from Swastika Nursery, over 200 kilometres away. Hence Swastika can soon turn its attention away from rooting juvenile cuttings, towards other tree improvement activities, such as grafting and controlled pollination. Already, trials are underway at Swastika to induce early flowering and cone production of jack pine. New greenhouses will be built at Swastika, strictly for tree breeding work.

Orono Nursery's only contribution to black spruce improvement is producing grafted stock for Northern Region seed orchards. In time, however, this task will be accomplished solely by Swastika Nursery.

Orono's Vegetative Propagation Centre is currently producing rooted cuttings of Norway spruce and tamarack. The spruce will be used to meet the high demand for planting stock in the Algonquin, Central, Southwestern and Northeastern Regions of the Province. The Eastern Region will receive 20,000 rooted tamarack cuttings for reforestation projects this year.

As of yet, Ontario's only conifer improvement program operates in the Northern Region. However, some of the regions in Southern and Central Ontario being supplied with Orono's clonal stock are interested in tree improvement. The major barrier to initiating a tree improvement program is insufficient funding.

THE IMPACT OF THE CANADA-ONTARIO FOREST MANAGEMENT SUBSIDIARY AGREEMENT ON SPRUCE IMPROVEMENT THROUGH VEGETATIVE PROPAGATION

COFMSA, the Canada-Ontario Forest Management Subsidiary Agreement, is a significant feature in the history of Ontario's conifer improvement work. The Agreement provided a powerful impetus, transforming clonal forestry from an ambitious idea into a forest management reality. If not for COFMSA, Ontario might still be talking about clonal forestry, without incorporating ideas into practice.

In a time of financial constraint, a Federal-Provincial Agreement can determine the future of an innovative new program. This makes the task of selecting among project proposals a very important one.

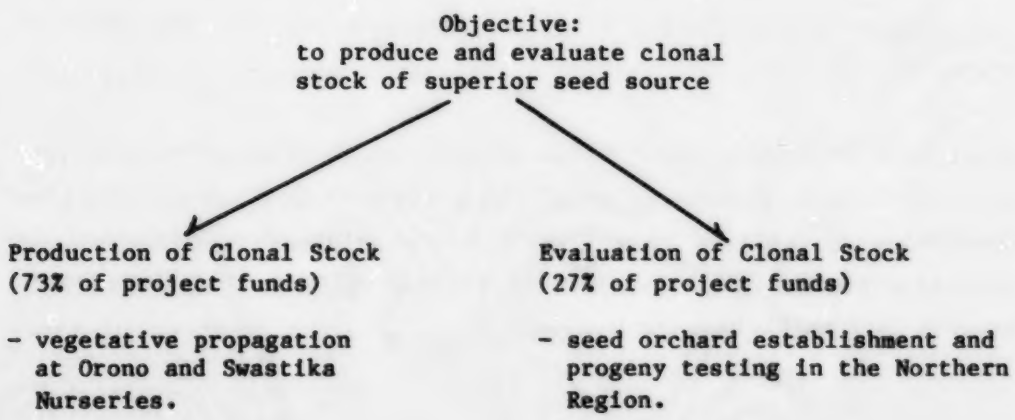
Recommendation 1

> The background and future potential of proposals submitted to a joint funding agreement should be well understood before a decision among proposals is made.

There were two facets to COFMSA's Tree Improvement Through Vegetative Propagation project: production of clonal stock and evaluation of clonal stock. Figure 2 outlines the project.

Figure 2

Outline of Tree Improvement Through Vegetative Propagation


Objective:
to produce and evaluate clonal stock of superior seed source
Production of Clonal Stock
(73% of project funds)
- vegetative propagation at Orono and Swastika Nurseries.
Evaluation of Clonal Stock
(27% of project funds)
- seed orchard establishment and progeny testing in the Northern Region.

The allocation of COFMSA's Federal-Provincial funds to the project is summarized in Table 6.

Table 6

Summary of COFMSA Funding to Tree Improvement Through Vegetative Propagation, 1980 - 1984

		Cost	% of total cost
I	Capital Expenditures - including greenhouses, header house, cold frames, greenhouse services and equipment		
(i)	Orono Nursery	$ 396,202	35
(ii)	Swastika Nursery	84,456	7
(iii)	Overhead Allowance	48,066	4
II	Study Expenditures		
(i)	Propagation of Orono and Swastika Nurseries	$ 307,276	27
(ii)	Seed Orchard Grafting at Orono Nursery @$7.50/graft	150,000	13
(iii)	Salary and travel expenses for tree improvement specialist in Northern Region	120,000	10
(iv)	Progeny tests in Northern Region, including tree selection, cone collection, site preparation, planting and tending	42,000*	4
		$ 1,148,000	100%

* The bulk of funding for progeny tests in the Northern Region was provided unilaterally by the Ministry of Natural Resources.

The greenhouses for rooting juvenile cuttings at Orono and Swastika Nurseries were the most obvious contributions of COFMSA to tree improvement through vegetative propagation. These facilities permitted a large-scale production of rooted cuttings that was not previously possible in Ontario.

In addition to this tangible output, COFMSA yielded some less obvious, but equally important benefits: it permitted valuable developmental work and generated important expertise.

The vegetative propagation facilities provided by COFMSA became centres for technology development. In the course of meeting provincial tree improvement demands, the practice of rooting juvenile black spruce cuttings was advanced substantially. Today, with the proper facilities and equipment, there is no reason for a black spruce juvenile cuttings program should experience at least 90% rooting success.

Invaluable expertise was generated during the COFMSA era. At Orono Nursery, the origin of juvenile cuttings work in the Province, Bernie Phillion and John deWitt became specialists in the field. DeWitt has since put his skills to work in Moonbeam for the Northern Clonal Forestry Centre. Bernie Phillion is now at the Thunder Bay Nursery, and would like to see a juvenile cutting program started there. Gibert Leveille quickly learned the necessary skill for rooting cuttings at Swastika Nursery. He is now involved in the early phases of a tree breeding program at Swastika.

Production of clonal stock under COFMSA may be regarded as a success story. It is a story of people working together and sharing their knowledge in achieving a common goal. It is a story of successful technology transfer. The technology development at the Orono Nursery operation is now embodied in the operations at Swastika Nursery and the Northern Clonal Forestry Centre.

The success of transferring rooting technology from Orono to Swastika and Moonbeam is largely attributable to the movement of people from one level of technology to another. Specialists came together with

newcomers to the field to share ideas and discuss problems. Technical literature produced by Phillion et al. played an important role in the technology transfer, but only to the extent that the literature was read and used.

Recommendation 2

> To facilitate prompt and effective technology transfer, there should be no barriers to the movement of people among components of a project. Personal interaction ought to be encouraged and supplemented with media such as scientific publications, research reports and information notes.

During the COFMSA era, the Northern Region was responsible for evaluating the clonal stock produced by Orono Nursery. The agreement provided a tree improvement specialist in the Region for three years. He conducted the first progeny tests and began to establish clonal orchards. In addition, the Agreement provided thousands of rooted cuttings of spruce clones, without which large-scale progeny testing could not be accomplished.

It is important to emphasize that the evaluation of clonal stock is incomplete. The COFMSA era was only the start, a preliminary phase to a tree improvement program which needs several more years before it is well developed. It would be premature to call the evaluation of clonal stock under COFMSA a success. In time, however, with more extensive progeny testing, the Tree Improvement Project will likely prove successful.

COFMSA can certainly give itself credit, however, for setting in motion one of the decade's most significant forestry undertakings.

Figures 3 and 4 illustrate the discrepancy between the annual expenditures originally proposed, and the actual annual expenditures for the project.

Figure 3

Original Estimates of Annual Expenditures for Project
(Total for 80/81 to 83/84 - $552,000)

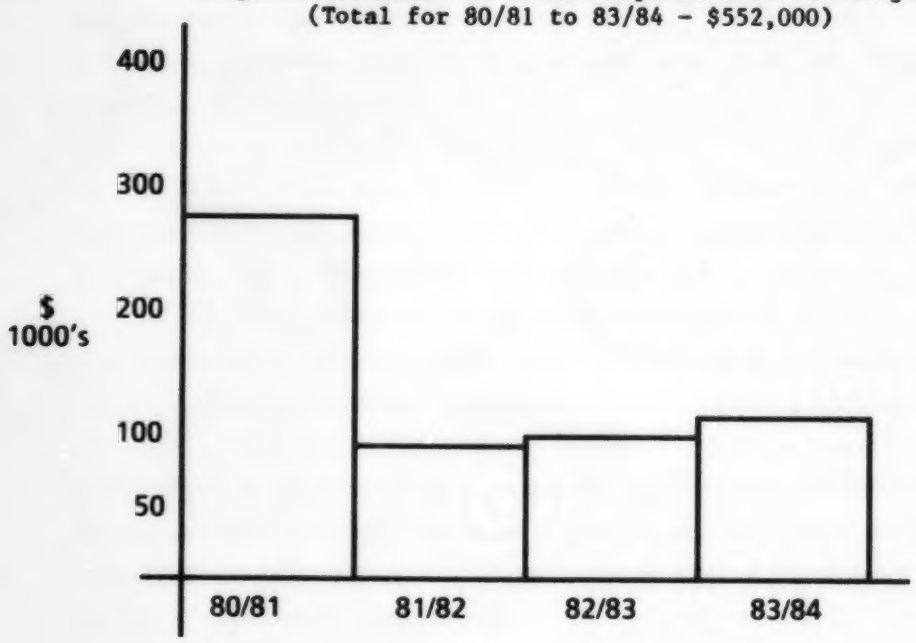
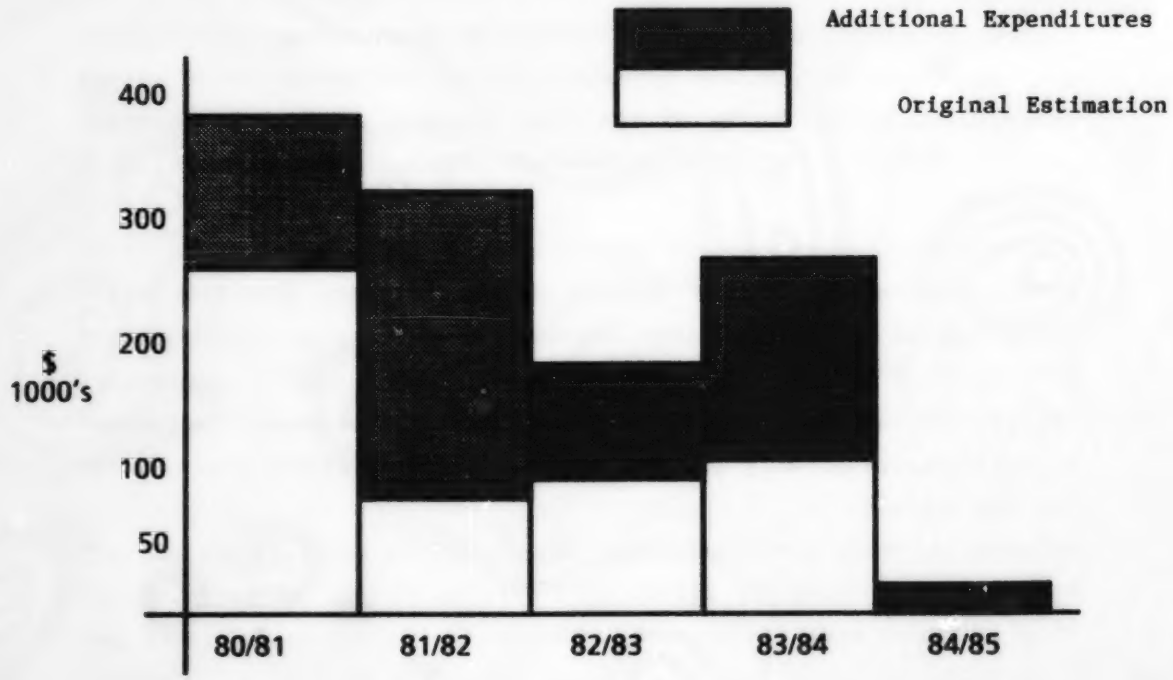


Figure 4

Actual Annual Expenditures for Project
(Total for 80/81 to 84/85 - $1,148,000)



The additional funding was needed to construct the greenhouse at Swastika Nursery and to support a seed orchard grafting program. Neither of these expenses were budgeted for in the initial proposal. The very labour-intensive task of keeping records of each clone produced and tested also required more money than was first expected. In adition, unexpected inflation and rising construction costs made the project more expensive than the first proposal indicated.

The initial project proposal underestimated the amount of money required to fulfill the project's objective. This created problems in planning production targets for rooted cuttings. A common complaint of the nurserymen at Orono and Swastika was that production figures for clonal stok were not provided soon enough. In nursery operations advanced planning is crucial to ensuring successful seedling crops. Timing is expecially important in a juvenile cuttings program where rooting success varies with the age of the donor plant and the time when cuttings are taken.

Recommendation 3

> Proposals should accurately estimate the annual expenditures required to fulfill project objectives. This will ensure well-planned and efficiently executed projects.

CLONAL FORESTRY AND TREE IMPROVEMENT IN ONTARIO: WHAT LIES AHEAD?

This report has discussed the role of spruce clones in speeding-up the process of tree improvement. There are several other advantages of clonal forestry which show immediate promise in Ontario.

Clonal testing will help to identify the black spruce clones which grow best on the various sites in Ontario's Boreal Forest Region. Some clones may be specifically adapted to particular soil conditions, while others might have a wider tolerance, adapted to a broad range of sites. It would be a tremendous asset to reforestation efforts if clonal planting stock were prescribed to sites according to soil type.

In Ontario, there is promise in using vegetative propagation to mass-produce clones of expensive genotypes. Hybrids, bred for certain genetic traits such as disease resistance, are difficult and expensive to propagate by conventional means. Rooted cuttings can overcome this problem. In addition, vegetative propagation can economically produce seedlings for species which are too expensive to collect seed from, such as tamarack.

These are some of the advantages of clonal forestry which show immediate promise in Ontario. A more complete discussion is given by Libby and Rauter (1984) and Rauter (1985).

Future Clonal Forestry Projects

Clonal forestry is an expensive endeavour, and a commitment to long-term funding is necessary to establish and maintain a clonal forestry program. The latest Federal-Provincial Agreement, the Canada-Ontario Forest Resource Development Agreement (COFRDA), will provide $5 million for tree improvement work, and $6 million for forestry research, development and application. Clonal forestry projects will qualify for funding under this agreement. This funding may give an important boost to conifer improvement work, as did funding from COFMSA, the previous Federal-Provincial Agreement.

Any new clonal forestry projects proposed in Ontario are subject to a Clonal Forestry Strategy, currently being drafted by R.M. Rauter, Supervisor of Tree, Seed and Genetics for the Ministry of Natural Resources. This strategy sets out guidelines and standards for using clones for tree improvement. The strategy considers the various advantages of clonal forestry, as well as biological and economic implications.

Research and Development Needs

As clones become more popular in forestry, the questions about their use become more abundant, and more important. A vast array of problems are now open for scientific investigation in the fields of clonal forestry and tree improvement.

A major question facing the future of clonal forestry is how to overcome the risks of early selection of donor trees. Rooting success is optimal when cuttings are made from donors in their juvenile state. The problem, however, is that in the juvenile state the genetic superiority of a tree is unconfirmed. This problem was a draw-back of the Super Seedling Program.

One solution to the problem of early selection is being pursued by Professor T. Blake of the University of Toronto's Faculty of Forestry. Blake is currently studying the physiology of juvenile cuttings, to attempt to find early indications of genetic superiority. He is using stock from the Northern Clonal Centre for his studies.

Another area of further research concentrates on donor trees. Maturation of donor trees must be retarded, so that cuttings may be made while the donor is at an early stage of development. The maturation of Orono Nursery's donor trees was partially retarded by serial propagation of rooted cuttings at Swastika Nursery. Another approach to slowing maturation is hedging of the donor trees to prevent upward growth. Ideally, the donor tree should be rejuvenated. Franclet (1985) has found that rejuvenation seems to occur when scions from mature trees are grafted and regrafted onto younger rootstock. This is an important area for further research.

A major concern with clonal forestry is the loss of genetic diversity. All trees in a given clone have the identical genetic constitution. They lack the necessary genetic diversity to tolerate a variety of sites and environmental conditions. Techniques to regulate the minimum number of clones in a plantation, and the maximum number of ramets per clone, are important safeguards for ensuring a balanced gene pool in a plantation. Research is required to develop a better understanding of regulating clonal production. In addition, out-planting strategies and management options for clonal plantations need to be further developed.

Clonal forestry will only succeed if biological as well as economic needs are met. There is plenty of opportunity for economic analysis in the tree improvement work. Cost-benefit analyses can compare the various tree improvement strategies including clonal forestry, and help to direct future planning and policy making.

It is beyond the scope of this report to discuss the future research needs of clonal forestry and tree improvement in any depth. More detailed discussions are provided by Rauter (1982) and Zsuffa et al. (1983).

CONCLUSION

Coniferous tree improvement in Ontario has a colourful history with many people contributing to its development and application. From the pioneering research of the 1940's to the mass production of rooted cuttings in 1985, conifer improvement work has exemplified the necessity for cooperation in forest management ventures.

The joint effort of the Canada-Ontario Forest Management Subsidiary Agreement facilitated a large expansive of the conifer improvement work initiated at Orono Nursery. This Federal-Provincial Agreement, however, was only the beginning. The successful application of agreement funding relied upon cooperation within the Ministry of Natural Resources. Orono Nursery, Swastika Nursery, and the Northern Region, each played a vital role in the Tree Improvement Through Vegetative Propagation Project of COFMSA. Together, these project components developed a pool of expertise and a wealth of experience which may be used in future tree improvement projects.

Conifer improvement work has added a new dimension to cooperation between the government and the private sector. Moonbeam's Northern Clonal Forestry Centre is a pioneering venture which demands the joint effort of the Ministry of Natural Resources and a private grower in order to succeed. If successful, the Centre may set a precedent for future private sector participation n tree improvement.

Cooperation must be the way of the future. Already, Ontario has entered into another major Federal-Provincial Forestry Agreement. This, and possibly future agreements, will bring innovative forest management proposals into reality. Joint funding agreements will also be valuable contributors to increasing the extent of research, development and application in forestry. Above all, they will present new challenges for cooperation in Ontario.

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APPENDIX B

PEOPLE INTERVIEWED FOR PROJECT ANALYSIS

1) Vegetative Propagation Specialists

D. Bouford, Technician, Orono Nursery
J. deWitt, Manager, Northern Clonal Foretry Centre
G. Leveille, Swastika Forest Station
G. McLeod, Superintendent, Orono Nursery
B.J. Phillion, Thunder Bay Nursery

2) Tree Improvement Specialists

J. Hood, Tree Improvement Coordinator, Ministry of Natural Resources
R.M. Rauter, Supervisor, Tree Seed and Genetics Unit, Ministry of Natural Resources
V. Wearn, Spruce Program Forester, Northern Forest Development Group, Ministry of Natural Resources

3) Agreement Administration

R.P. Alton, Special Projects Coordinator, Timber Sales Branch, Ministry of Natural Resources
J.H. Cayford, Regional Director, Great Lakes Forest Research Centre, Canadian Forestry Service
R.A. Haig, Program Director, Forestry Development, Great Lakes Forest Research Centre, Canadian Forestry Service
K.G. Higgs, Agreement Administrator, Canada-Ontario Forest Resource Development Agreement.

4) Contact on Project History and Development

K.A. Armson, Executive Coordinator, Forest Resources Group, Ministry of Natural Resources

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